NASA LEWIS F100 ENGINE TESTING

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SUMMARY

Two builds of an F100 engine model derivative (EMD) engine, serial number XD11, were evaluated in the NASA Lewis Research Center (LeRC) propulsion system laboratory (PSL) altitude facility for improvements in engine components and digital electronic engine control (DEEC) logic. Two DEEC flight logics were verified throughout the flight envelope in support of flight clearance for the U.S. Air Force (USAF) F100 Engine Model Derivative Program (EMDP). A nozzle instability and a faster augmentor transient capability were sucessfully investigated in support of the F-15 DEEC flight program. Also included are identification of an off-schedule coupled-system mode fan flutter, DEEC noseboom pressure correlation, DEEC station 6 pressure comparison, and a new fan inlet variable vane (CIVV) schedule.

INTRODUCTION

An F100 EMD engine, serial number XD11, was tested in the LeRC PSL facility for altitude evaluations of advanced engine components and DEEC control logics. Two engine builds have been investigated at this time. Build 11 supported part of the flight clearance portion of the Air Force F100 EMDP. Two DEEC flight logics for this program were verified for use in F-15 flight testing that began in March of 1983. Build 10 underwent fan flutter and fan performance evaluations. Build 10 was also used in support of a F-15 DEEC flight program, specifically in the areas of nozzle stability (ref. 1) and augmentor performance upgrade.

The test conditions for these flight support tests are summarized on the engine flight envelope. In addition, results of the fan flutter investigation, noseboom and station 6 pressure probe correlations for DEEC control inputs, and some engine performance at axially off-schedule CIVV positions, and presented.

NOMENCLATURE

AJ	jet primary nozzle area
BOM	bill of material
CIVV	compressor inlet variable vane

DEEC	digital electronic engine control
EMD	engine model derivative
EMDP	Engine Model Derivative Program
EPR	engine pressure ratio, PT_{6M}/PT_2
FDA	failure detection and accommodation
FTIT	fan turbine inlet temperature
IM	intermediate power
LOD	light off detector
N1	fan rotor speed
O.D.	outer diameter
PES	photo electric scanning
PLA	power lever angle
PLA-AB	afterburner power lever angle
PS_{NB}	noseboom probe static pressure
PT_2	fan inlet total pressure
PT_2 UNDIST	undistorted (maximum) fan inlet total pressure
PT_{6M}	turbine discharge total pressure (mixed core and fan stream)
P6M01	turbine discharge total pressure production probe
SFDV	single flow divider valve
seg	augmentor spray ring segment
TT_2	fan inlet total temperature
Wa_1	fan inlet total airflow
δ_2	ratio of fan inlet total pressure to standard sea level static pressure
θ_2	ratio of fan inlet total temperature to standard sea level static temperature

APPARATUS

Engine

Tests were conducted with a F100 EMD (Pratt and Whitney Aircraft designation PW1128) engine, serial number, XD11. This engine is a low-bypass, high-compression ratio, twin spool turbofan with a mixed-flow augmentor. The EMD engine is similar to the production F100 but has a new advanced fan design, improved high-pressure compressor, a recontoured combustor, a higher-temperature capability turbine system, an advanced fuel management (AFM) augmentor system, and a DEEC control system.

Evaluations were made with two engine builds (10 and 11). XD11-10 had a six-segment augmentor instead of the AFM. For the F-15 DEEC flight support tests, the ducted-core augmentor flameholder of XD11-10 was replaced with an F100 bill of material flameholder. XD11-11 had a redesigned third-stage fan, high-pressure compressor modifications, and the low-pressure AFM augmentor system. During tests with XD11-11, the single flow divider valve (SFDV) main fuel system was replaced with the F100 bill of material fuel system, and the AFM augmentor was updated with the high delta-pressure spray rings.

Fuel Control

A breadboard version of the DEEC was used. This unit provided the capability of modifying control loops, logic, and schedules, both on and off line. A further description of the DEEC is given in reference 1.

Facility

Engine tests were conducted in an altitude test chamber of the LeRC PSL. The altitude facility includes a forward bulkhead which separates the inlet plenum from the test chamber. Conditioned air at the desired inlet pressure and temperature flowed from the inlet plenum through a bellmouth and inlet duct to the engine. The test chamber was evacuated to the desired altitude pressure. Exhaust from the engine was captured by a collector which extended through the rear bulkhead of the test chamber.

TESTS AND RESULTS

F100 EMD Flight Support Tests

Logic Verification and Fault Detection and Accommodation. Figure 1 shows the flight envelope test conditions for the DEEC logic verifications and the DEEC fault detection and accommodation (FDA) tests using XD11-11. The logic verifications were a final check of the logic operability throughout the flight envelope before manufacture of the flight DEEC units (burning the programmable read-only memories (PROMs)). The PD 4.2.0 designation corresponds to the AFM augmentor system and incorporates all of the logic improvements made since an earlier version (PD 4.1.1) was defined.

PD 4.2.1 logic has some additional stall recovery improvements. PD 4.2.0 logic verifications included augmentor transients, bodies, closed-loop starts, and a zoom climb. Of the supersonic points, augmentor transients were evaluated only at Mach 1.6 and 35,000 ft altitude condition.

The PD 4.2.1 tests included gas generator transients, augmentor transients, and bodies for the stall recovery logic verifications. In addition, PD 4.2.1 included a post-stagnation spooldown airstart, part power jet primary nozzle area (AJ) scheduling to lower sea level fan turbine inlet temperature (FTIT), and AJ oscillation with power lever angle (PLA) noise investigations. The DEEC FDA tests included steady-state and transient engine running for verification of DEEC parameters, demonstration of operation with failed inputs, and transfer to secondary control mode with high-sensed burner pressure.

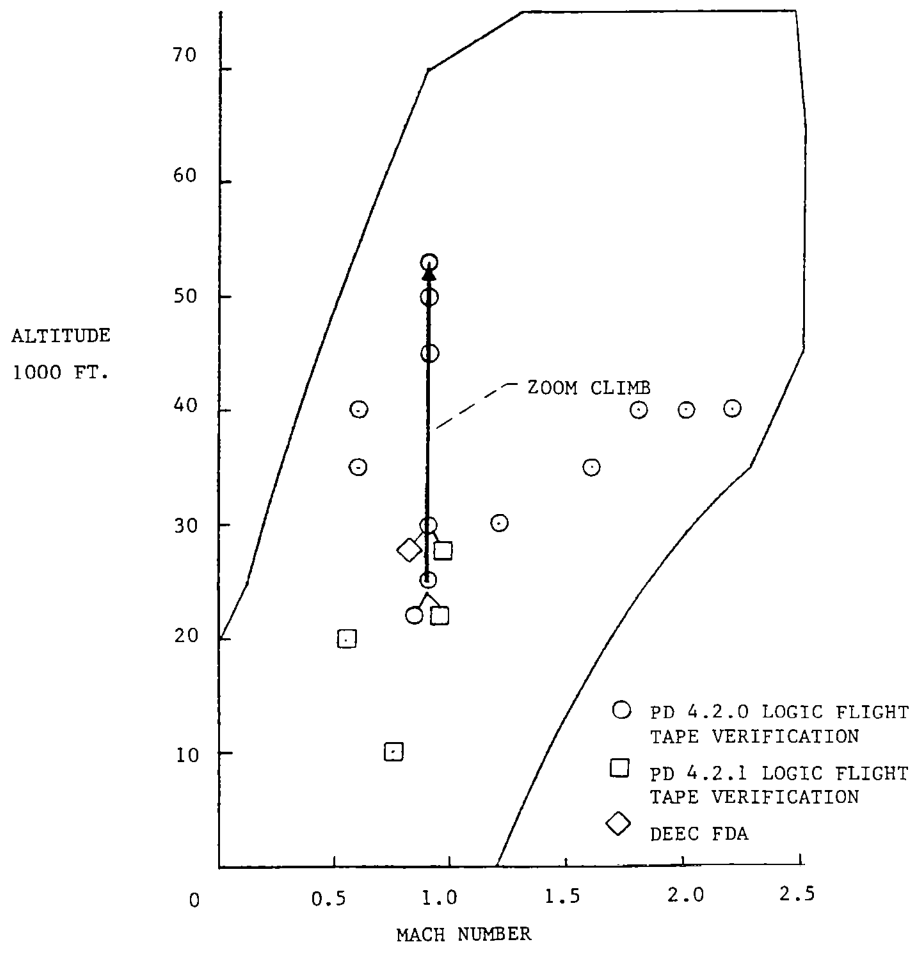

Fig.1 - XD11-11 EMD FLIGHT SUPPORT - DEEC LOGIC VERIFICATION AND FDA

Stall Recovery and Bodie Test Points. The test conditions for stall recovery and bodie evaluations are shown in figure 2. The stall recovery of both PD 4.2.0 and PD 4.2.1 logics was demonstrated with high-power stalls which utilize a delayed augmentor ignition to create an engine stalling pressure pulse. The recovery demonstration was well within the success criteria as only one nonrecoverable stall occurred out of more than 60 attempts. This stagnation was at Mach 0.6 and 40,000 ft altitude with the PD 4.2.1 logic.

Individual removal of bodie stall protection logics were evaluated at two conditions. With all the protection logic removed, a bodie stall occurred at Mach 0.8 and 45,000 ft altitude condition. Bodie stall margin was demonstrated at three flight conditions with idle dwells varying from 3 to 60 sec. Stall margin was verified by increasing the fuel flow during the acceleration portion of the bodie; this fuel flow addition moved engine operation closer to the stall line. No engine stalls were found. At 40,000 ft altitudes, successful bodie stall margin was demonstrated with both the single flow divider valve and F100 BOM fuel systems. Only the SFVD system was tested at 30,000 ft.

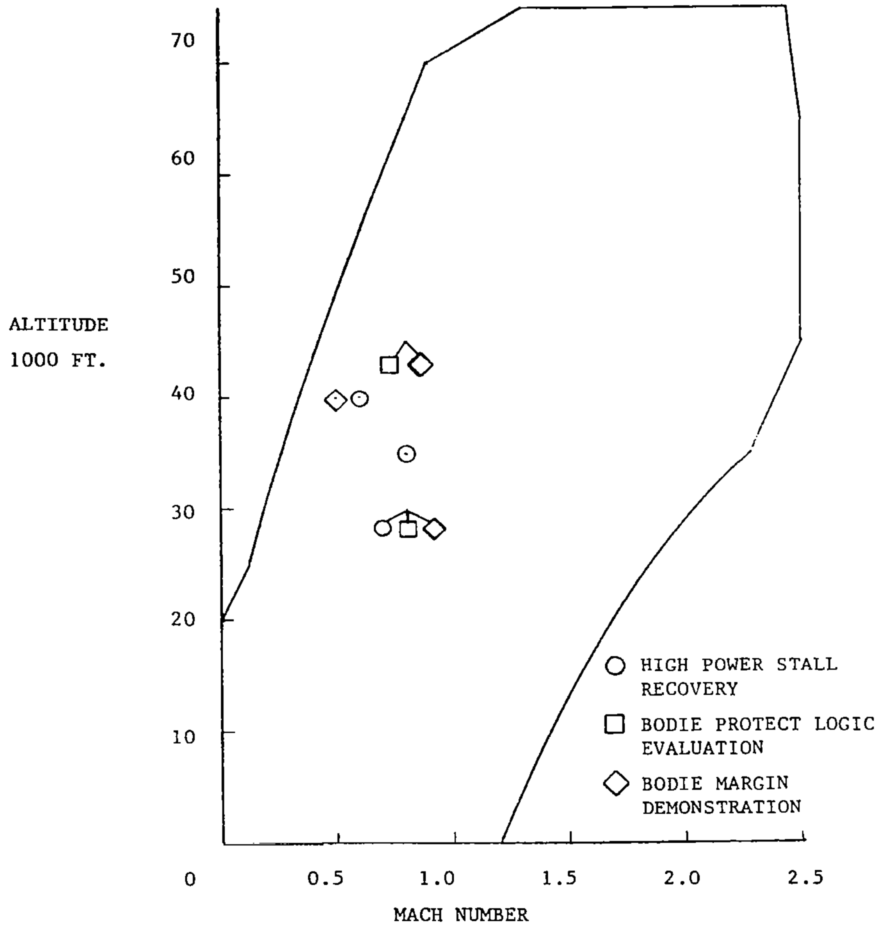

Fig.2 – XD11-11 EMD FLIGHT SUPPORT

– STALL RECOVERY AND BODIE TEST POINTS

Spooldown Airstart Test Points. Figure 3 shows the spooldown airstart test conditions. With the SFDV fuel system and ambient fuel, four unsuccessful starts occurred with 40-percent spooldown attempts. Because of suspected fuel vaporization problems, the SFDV system was replaced by the F100 BOM fuel system. Using hot fuel and the BOM fuel system, successful airstarts were recorded at 200 knots for 40-percent and 25-percent spooldown for primary control mode and 40-percent spooldown for secondary mode. At 300 and 350 knots, successful 40-percent spooldown airstarts were recorded for both primary and secondary modes with the BOM system and hot fuel. Also, at 350 knots and 10,000 ft altitude, a 25-percent spooldown airstart for primary mode was recorded.

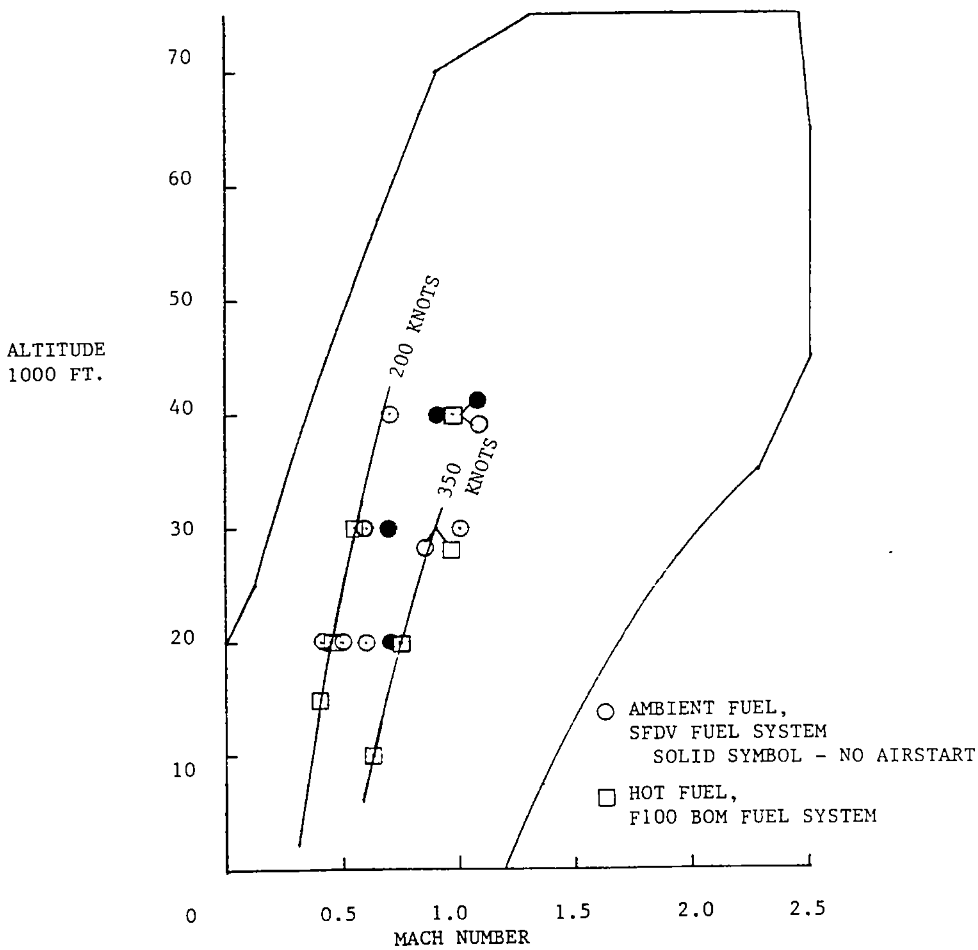

Fig.3 - XD11-11 EMD FLIGHT SUPPORT

- SPOOLDOWN AIRSTART TEST POINTS

F-15 Flight Support Tests

Figure 4 shows the exhaust nozzle stability and light off detector (LOD) fast acceleration optimization investigations conducted with XD11-10. With the F100 BOM augmentor flameholder and XD11-10's six-segment spray rings, representative tests for the F100 flight engine (P063) could be made at altitude conditions in the ground-level facility.

The F-15 DEEC flight program encountered AJ nozzle oscillations during augmentation, which had not been predicted from previous tests and could not be reproduced with engine/control simulations. The engine pressure ratio (EPR) control loop nozzle instability was investigated at the four conditions shown. Using the DEEC breadboard to vary control constants, nozzle stability could be controlled with a reduction in the EPR/AJ loop gain. This evaluation with XD11-10 has been reported in reference 1.

XD11-10 was also used to verify DEEC control and augmentor upgrades for the DEEC flight program. An augmentor LOD and DEEC fast-acceleration logic was successfully demonstrated and optimized at the test conditions shown here. For this engine, augmentor transients to segments 4 and 5 are shown above the F100 segment 1 transient limiting boundary. To acheive these transients, DEEC breadboard logic included modifications of segment 1 limit, segment 5 redistribution, segment 1 hold, afterburner power level angle (PLA-AB) rate, AJ schedule, and fuel schedule. This again demonstrates the flexibility of the breadboard unit.

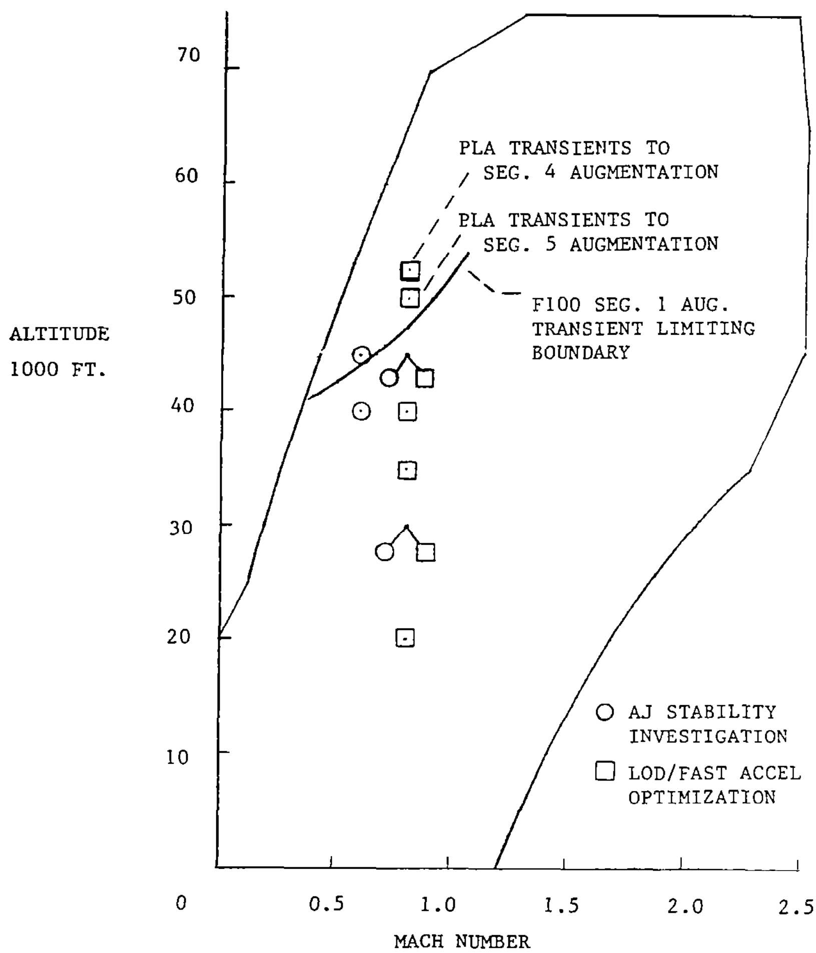

Fig.4 – XD11-10 DEEC FLIGHT SUPPORT – TEST POINTS

XD11-10 Results

Compressor Inlet Variable Vane Excursions. An extensive fan flutter investigation was conducted with XD11-10 throughout the flight envelope. Blade flutter was monitored by a photo electric scanning (PES) system and by strain gages which required the use of a slip ring assembly. Seven flutter points were found by taking the fan inlet variable vanes (CIVVs) off schedule with the breadboard control. This flutter is a fan-coupled-system mode of rotor 1. The corresponding fan inlet total pressure (PT_2), fan inlet total temperature (TT_2) and screen is indicated on figure 5.

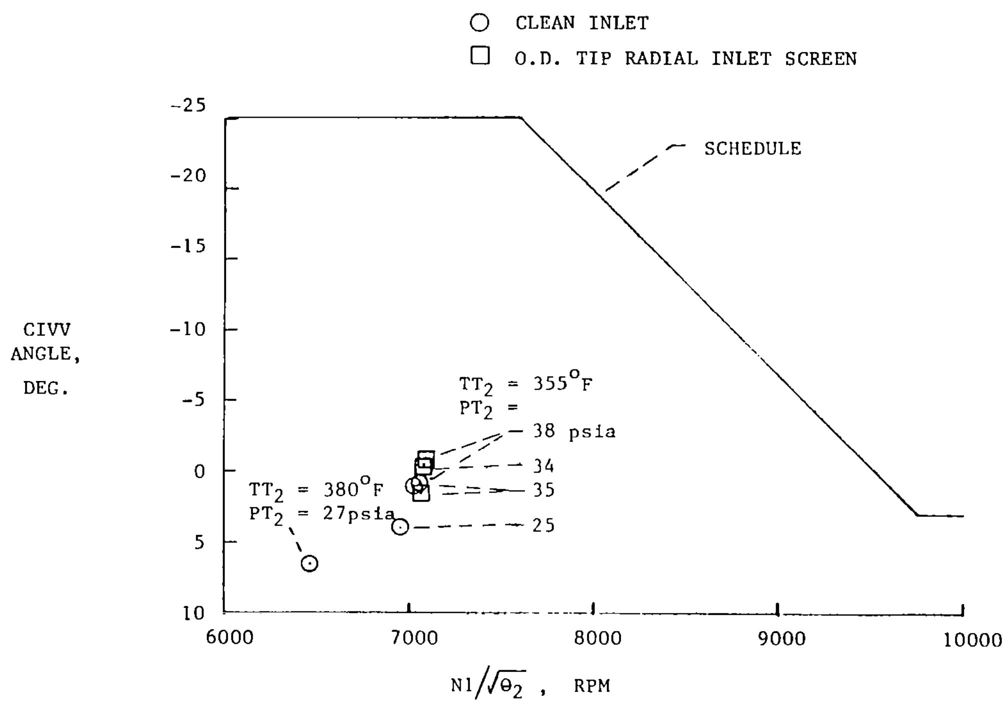

Fig.5 – XD11-10 FLUTTER POINTS – CIVV EXCURSIONS

Pressure-Airflow Correlation. Upon completion of the flutter program, the slip ring was removed, and the DEEC noseboom probe was installed. Figure 6 shows the noseboom pressure-airflow correlation at two pressure levels for the XD11-10 engine. Also included is an F100 engine (P072) correlation from reference 2. The P072 airflow is the unadjusted, originally measured airflow. The 1-percent difference could be a result of the nonlinear transducer corrections, which were not used with the P072 data, and of possible improvements in pressure averaging and airflow calculation.

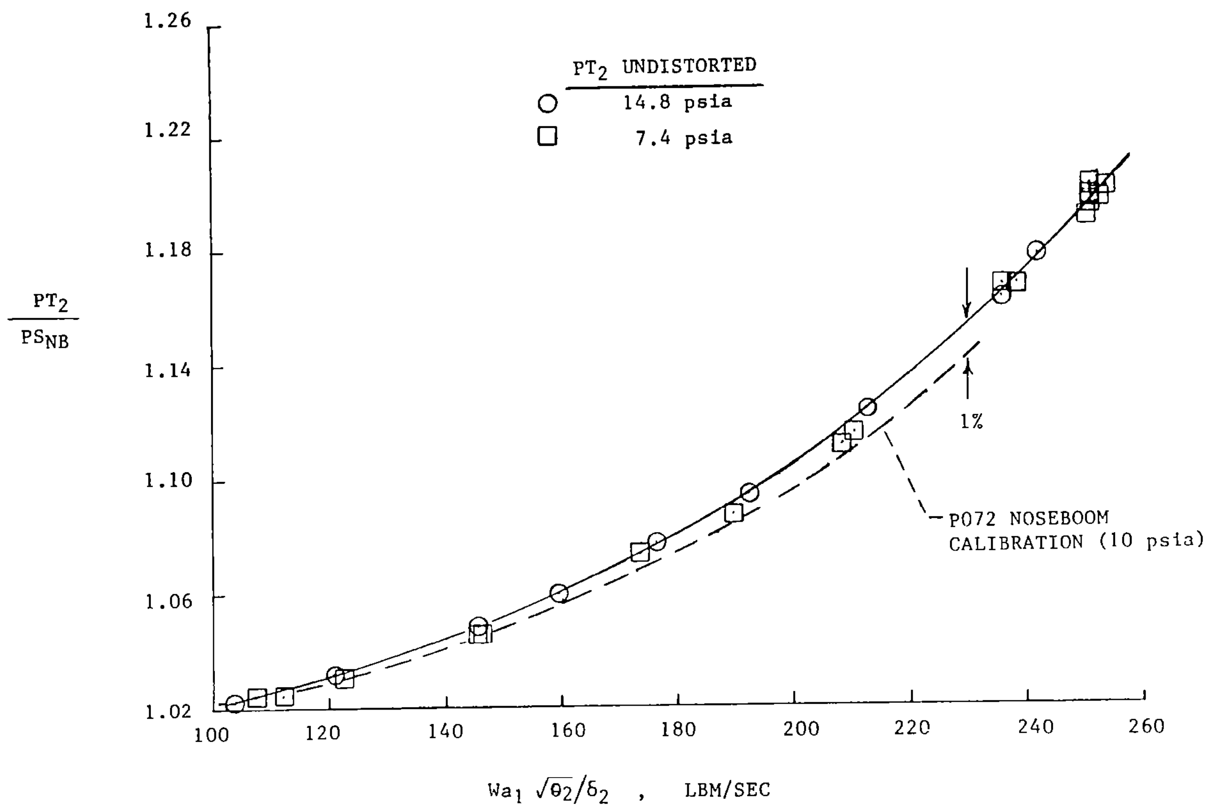

Fig.6 - XD11-10 PT/PS NOSEBOOM CORRELATION - CLEAN INLET

Noseboom Correlation. Figure 7 shows the noseboom correlation for two inlet screens — a radial and a circumferential. Data for both of these screens are nearly the same and lie about 4.5 percent above the clean inlet correlation.

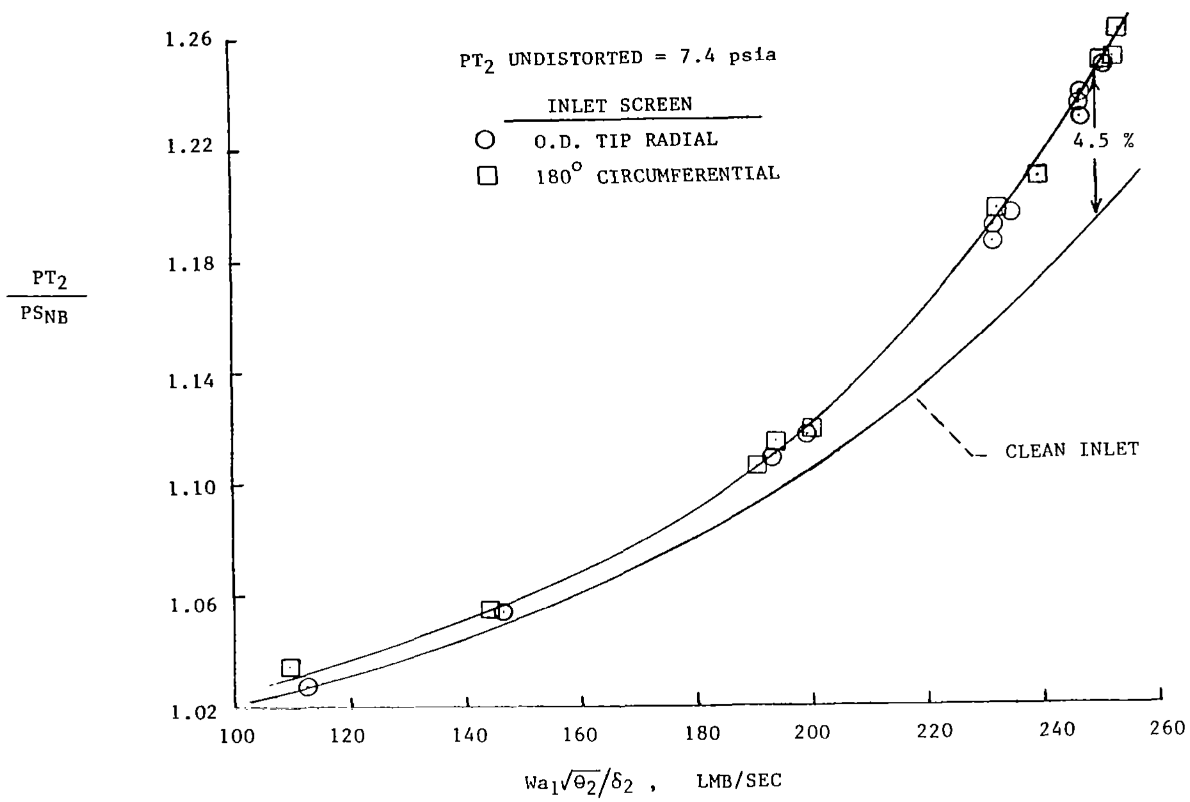

Fig.7 – XD11-10 PT/PS NOSEBOOM CORRELATION – INLET SCREENS

Inlet Total Pressure Recovery. The engine inlet pressure recovery for the clean inlet and inlet screen conditions is illustrated in figure 8. The recovery here is the ratio of the average to the undistorted or maximum average pressure at the engine inlet. Recovery levels at intermediate power (IM) are about 99 percent for clean inlet, 95 percent for the radial screen, and 90 percent for the circumferential screen.

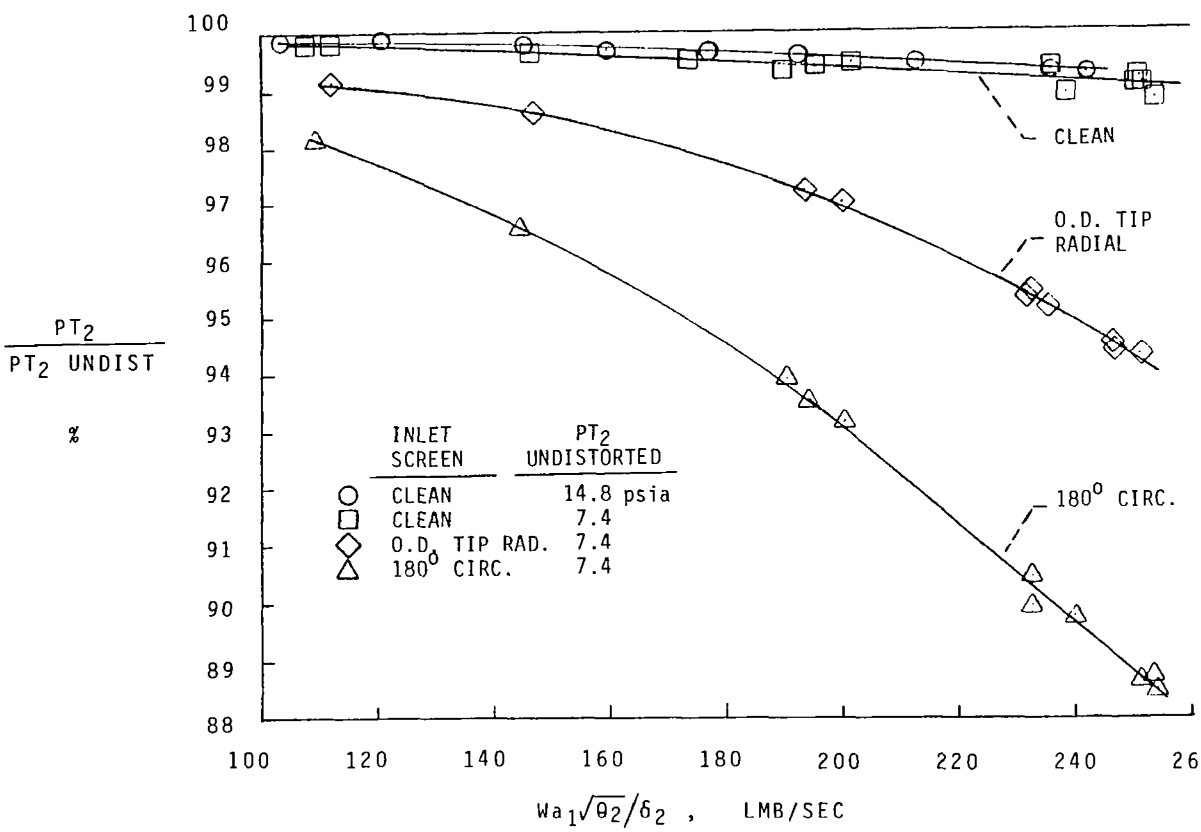

Fig.8 - XD11-10 INLET TOTAL PRESSURE RECOVERY

Comparisons. Figure 9 compares the engine station 6 DEEC turbine discharge total pressure production probe (P6MO1) to the mass-weighted average. The data is for engine speeds at IM and above when the DEEC is on EPR control for both clean inlet and inlet screens. The 0.6 percent variation is nearly the same as reported in reference 2 (0.5 percent).

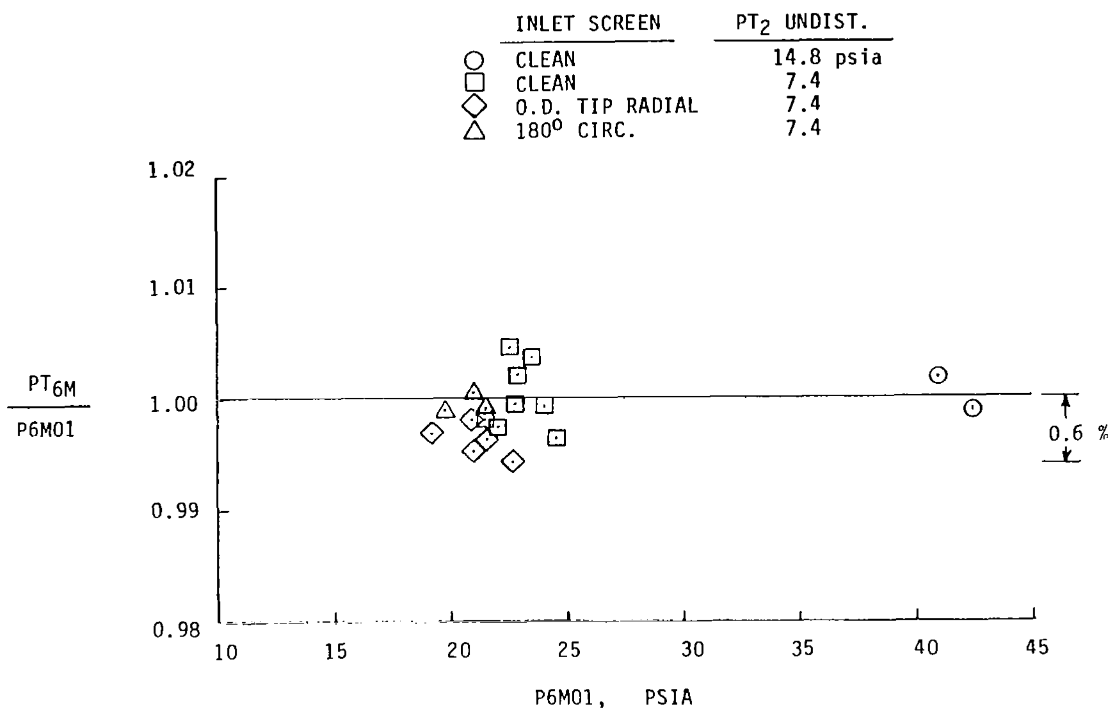

Fig.9 – XD11-10 COMPARISON OF DEEC P6M PROBE TO PT6M – ENGINE SPEEDS AT I/M POWER AND ABOVE

Variations With Speed, Airflow, and Pressure. At the end of the XD11-10 test program, the CIVV schedule was found to be set open (axial) by 10°. The following three figures show CIVV variations with corrected fan speed, corrected total airflow, and engine pressure ratio (EPR). Based on XD11-10 testing and a CIVV variation investigation with an F100 EMD engine (FX227-12) at Arnold Engineering Development Center (AEDC), a new CIVV schedule resulted and is shown in figure 10. An increase in airflow with open CIVV is shown in figure 11 with maximum airflow occurring between CIVV angles of 10° and 15° open. Figure 12 shows the increase in EPR as CIVVs are opened.

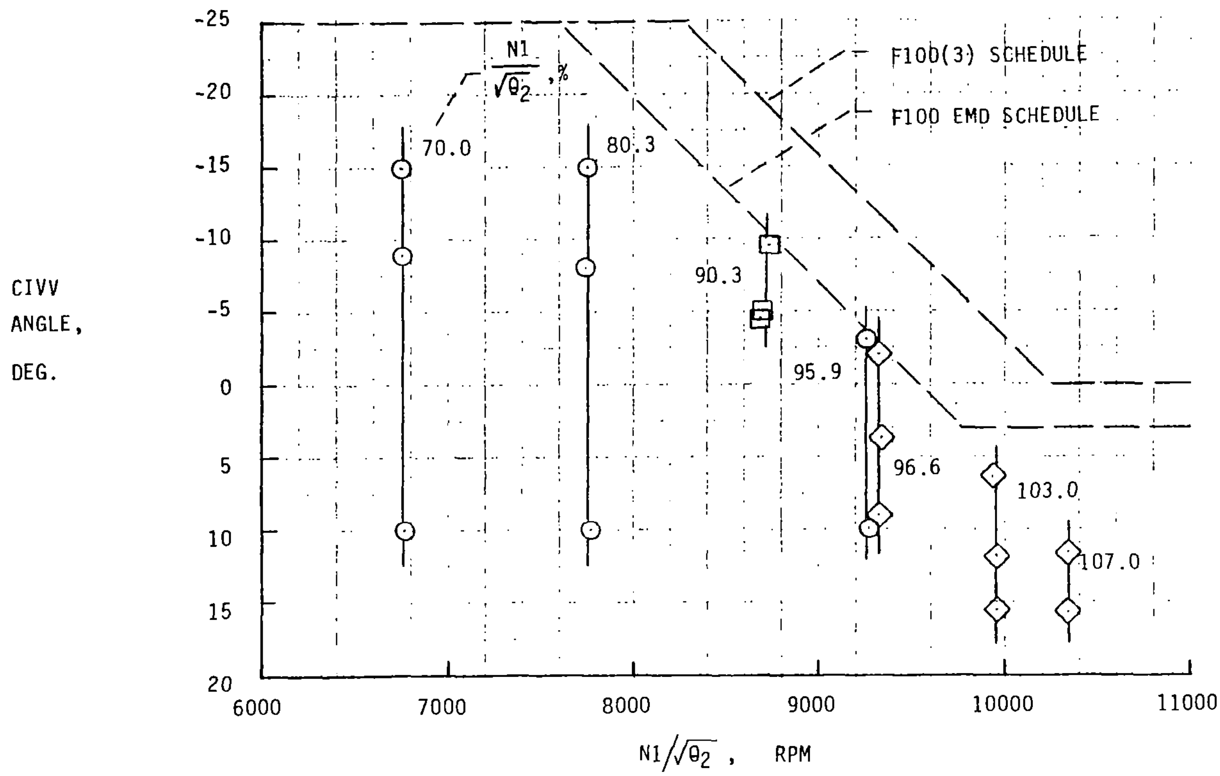

Fig.10 – XD11-10 CIVV VARIATION VS CORRECTED FAN SPEED

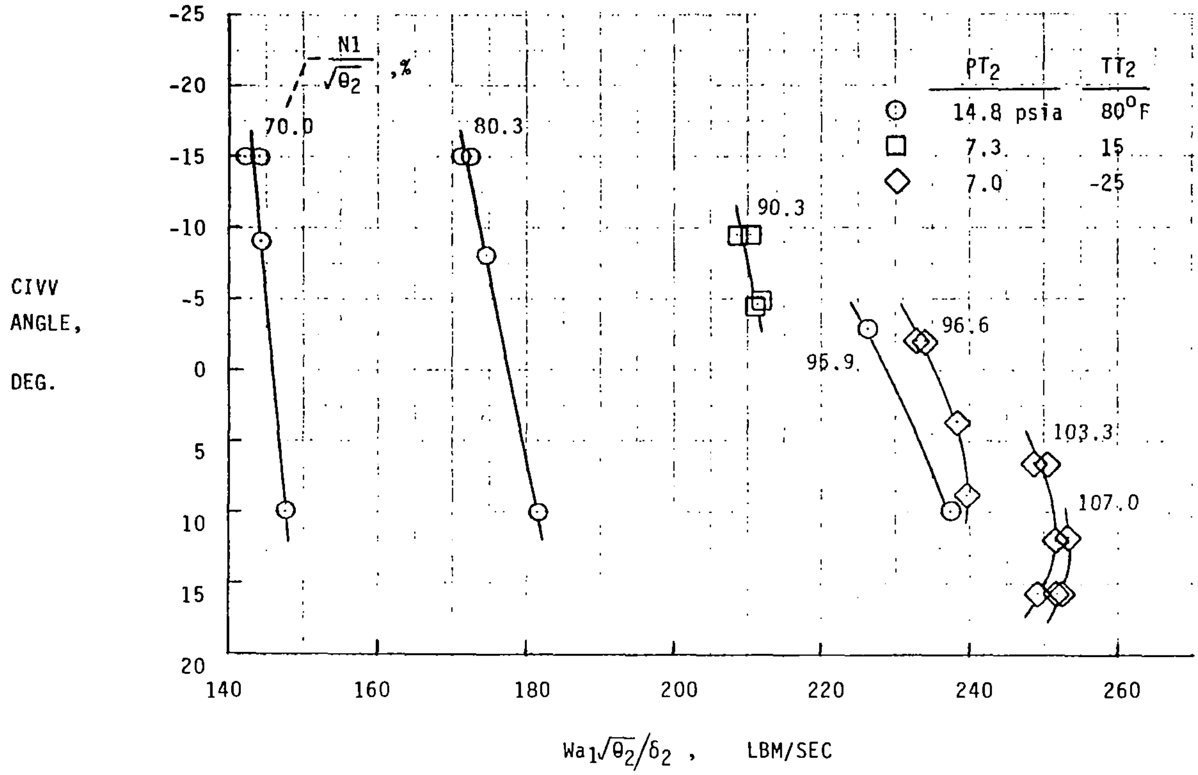

Fig.11 – XD11-10 CIVV VARIATION VS CORRECTED TOTAL AIRFLOW

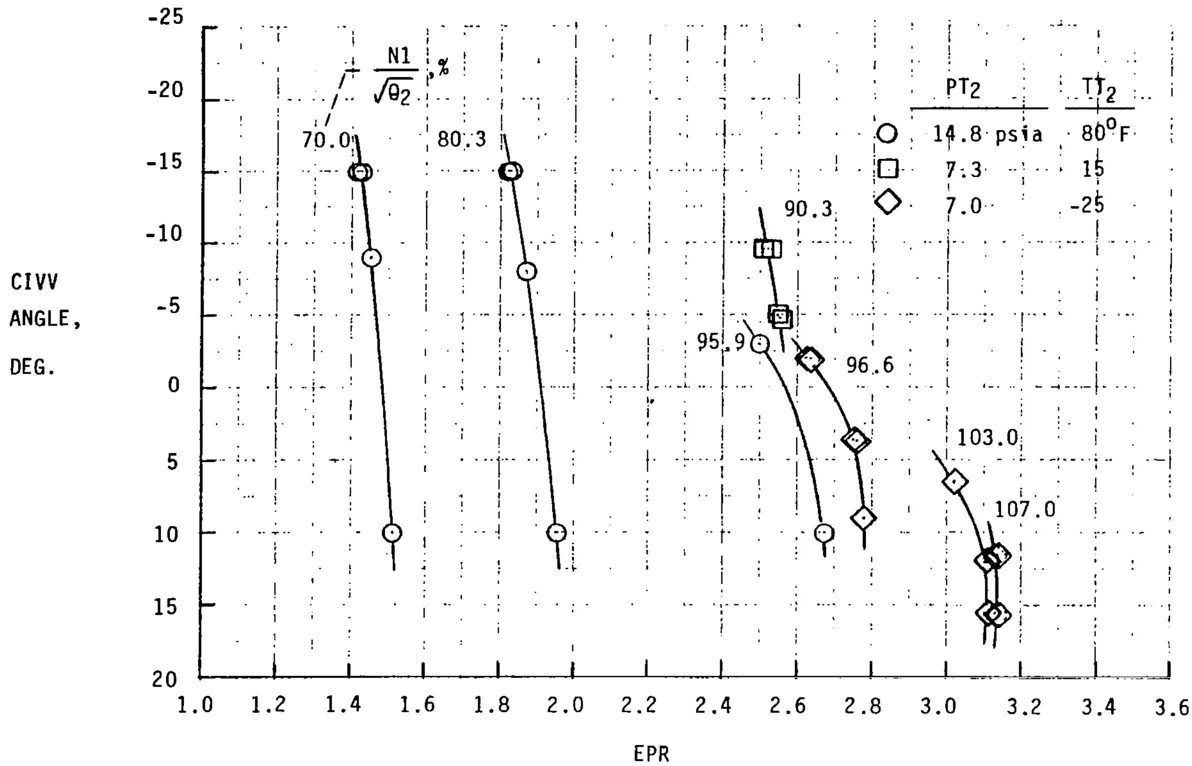

Fig.12 – XD11-10 CIVV VARIATION VS ENGINE PRESSURE RATIO, EPR

CONCLUDING REMARKS

Some of the results of evaluations with the XD11-11 and XD11-10 engine are summarized as follows:

(1) Two DEEC control flight logics were verified for F100 EMD flight tests.

(2) An EPR control loop nozzle instability was successfully investigated.

(3) The LOD/fast acceleration was optimized, resulting in five-segment augmentor system transient operation above the previous F100 limits.

(4) An earlier version of the F100 EMD fan was cleared of flutter throughout the flight envelope. An off-schedule CIVV fan-coupled system mode flutter for rotor 1 was identified.

(5) DEEC noseboom and P6M01 measurements performed satisfactorily.

(6) A new CIVV schedule for increased airflow was formulated.

REFERENCES

1. Burcham, F.W., Jr.; Myers, L.P.; and Zeller, J.R.: Flight Evaluation of Modifications to a Digital Electronic Engine Control System in an F-15 Airplane. AIAA Paper 83-0537 (NASA TM-83088), Jan. 1983.

2. Foote, C. H.: Data Analysis of PT/PS Noseboom Probe Testing on F100 Engine P680072 at NASA Lewis Research Center. NASA CR-158816, 1980.